MINE SHAFT CONVEYANCE MONITORING

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ABSTRACT

Technology to enhance safety during mine hoisting has been developed by researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health. Assessment of current hoisting technology suggests that monitoring conveyance position and load directly from the skip or cage top offers several significant safety advantages. Wireless data transmission schemes and a package consisting of sensors, batteries, and a charger mounted on the wire rope and skip have been developed. A state-of-the-art automated hoisting test facility was constructed to test the concept in a controlled laboratory setting. Field tests in a full-size shaft are underway.

INTRODUCTION

The shaft is the lifeline to underground mines, and miners depend on safe, uninterrupted, and efficient flow of materials. The shaft and hoisting system provide access to the network of openings used to recover the underground resource, provide vertical transport of miners and materials, and serve as an escapeway in case of emergency.

Hoisting accidents resulting in injury are relatively uncommon, but all hoist accidents have the potential to be catastrophic. For example, at the Markham Colliery in Derbyshire, UK, in 1973, a conveyance overwound and fell to the pit bottom, resulting in 17 deaths.

According to Mine Safety and Health Administration (MSHA) data, many shaft-related accidents in the United States are associated with the hoisting and loading-unloading cycle. For example, a condition known as "slack rope" is particularly dangerous, especially if it occurs without the operator's awareness. Causes of slack rope in metal and nonmetal mines are often ground control or guide alignment problems, which can cause the cage or skip to become obstructed. Other hazards are related to falls of miners and materials, ground instability, and malfunction of safety devices. Figure 1 shows the causes of hoisting accidents over the period 1992-96.

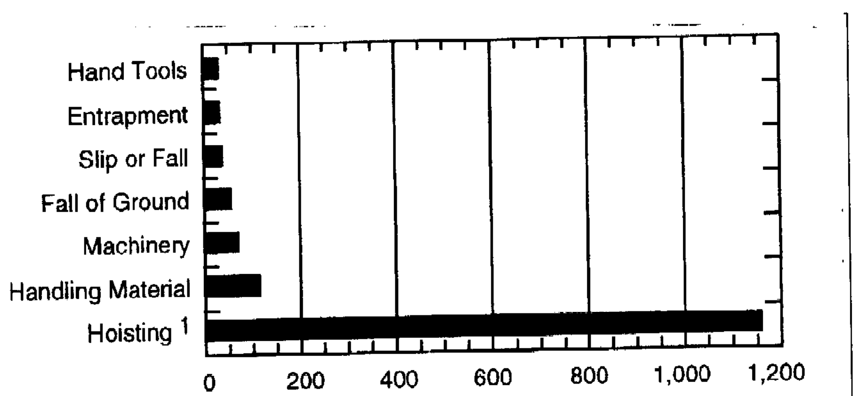

Figure 1.—Causes of hoist accidents, 1992-1996. [1]Accident involving cages, skips, ore buckets, and elevators.

In response to a request from MSHA to improve the safety of mine hoisting, researchers at the Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH) have developed new technology for hoisting operations. The immediate goal of the research is to improve shortcomings of existing safety controls by increasing the quantity and quality of data related to the operation of mine hoists and to develop means of warning miners about potentially dangerous situations.

Hoist and elevator machinery must meet the requirements specified in the Code of Federal Regulations (CFR), Parts 57 and 75. Earlier investigators defined safety features and operating and maintenance standards for hoists and reported on monitoring and control systems and sensors for hoists and conveyances [1-2]. Based on these investigations, SRL researchers determined that there are several shortcomings in hoist monitoring technology. These are (1) lack of accurate measurements of wire rope tension and conveyance load and position, and unreliable transmission of data up the shaft and (2) the inability to test new hoisting technology in a controlled setting. This paper describes a sensor and data acquisition system to monitor mine hoist conveyances and a research facility to test these components.

CONVEYANCE-MOUNTED MONITORING SYSTEM

Development of a shaft conveyance-mounted monitoring system has focused on a maintenance-free, unobtrusive package for determining position, load, wire rope tension, and guide displace-ment. Previous work [3] described initial concept development. The current work involves laboratory and field evaluations of sen-sors, data transmission schemes, and data processing and display.

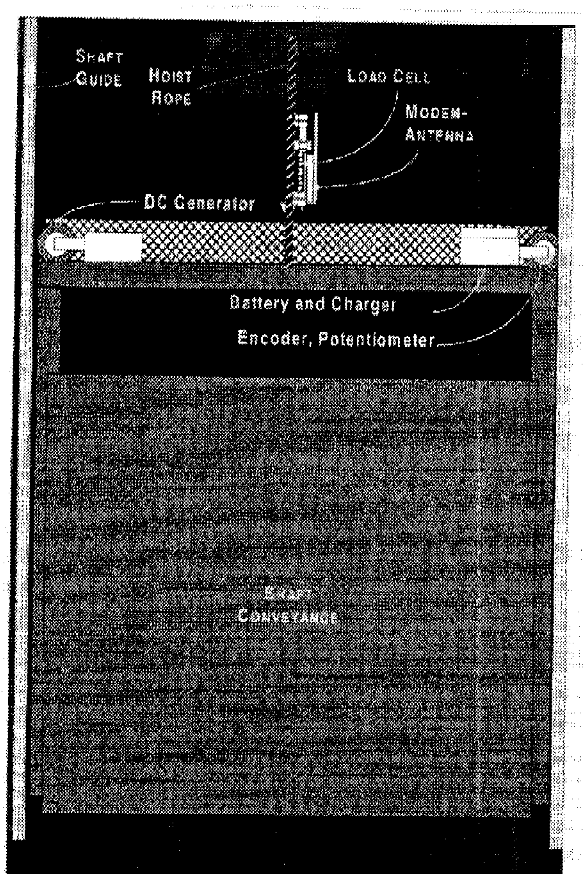

Figure 2.—Concept for instrumented skip.

The system described here is designed to provide hoist operators and maintenance and inspection personnel with a real-time indication of the operational status of a mine shaft hoist conveyance. Figure 2 shows the concept as con-figured on the top of a skip. It consists of three sensors: a "Flex-Beam" load cell (patent 5,728,953), an optical encoder, and a potentio-meter. The load cell, attached to the wire rope just above the conveyance termination with a Crosby clip, indicates wire rope tension and conveyance weight. Conveyance position, speed, and acceleration are determined from the encoder data. Displacement of the shaft guides is measured with the string potentiometer. Bat-teries are charged continuously during move-ment of the cage or skip up or down the shaft.

A custom-designed data acquisition package was developed for processing the sensor signals and converting data to a format suitable for computer input. The package includes a battery-powered, microcomputer-controlled, signal-processing board (SPB), a spread-spectrum radio modem, and rechargeable batteries. The SPB monitors and processes data from two analog channels and one digital channel and provides optically isolated serial data output. The analog channels are configured as a 16-bit, full-bridge, strain gauge channel for the load cell, and an 8-bit channel for the potentiometer. Data are processed and transmitted for display locally to a handheld device, as well as transmitted via a 2.4-GHz spread-spectrum modem or a 138-MHz data radio and leaky feeder cable to a computer in the hoist room or shaft station. A computer displays conveyance weight, wire rope tension, conveyance position, speed, acceleration, guide displacement, battery voltage, and temperature from the conveyance system. The display is updated 20 times per second. For a conveyance traveling at 360 m/min or 6 m/s (1200 ft/min or 20 ft/s), this sampling rate provides data for every 30 cm (1 ft) of conveyance travel. The handheld display device provides the capability of showing hoist data independently of the hoist computer via a 916.5-MHz onboard radio data link. The range of the line-of-sight radio link is 33 to 66 m (100 to 200 ft). The radio link is intended to be a tool for a shaft inspector or a maintenance person, as well as desktop indicator of hoist data that can be read in the hoist room.

MINE HOIST RESEARCH FACILITY

Figure 3 shows the layout of the closed-loop mine shaft and hoisting test facility. Ore is initially loaded through a ground-level grizzly into a gated, below-ground discharge chute and loading cartridge, and then into the skip. The skip hoists the ore to the top of the headframe, where it is dumped into a hopper. The ore is gravity-fed through a one-third-scale mockup of an ore pass chute and gate system. The material is then dumped into the below-ground hopper and loading pocket, completing the loop.

A state-of-the-art, computer-based system controls the hoist motor, ore chute gates, and related hoisting functions. Hoisting and loading operations can be controlled manually or the system can be allowed to cycle automatically through the loading, hoisting, and dumping process. Motor control is achieved with a Saftronics DCM-series motor controller. An automatic tuning procedure provides feedback parameters for precise motor control. Limit switches are mounted near the top and bottom of the shaft. The limit switches are closed as the skip passes, which activates the appropriate motor speed (800 or 50 rpm) or stops the skip at the station. Motor speed feedback is achieved with a Rotopulser encoder and a Dynapar frequency-to-voltage converter.

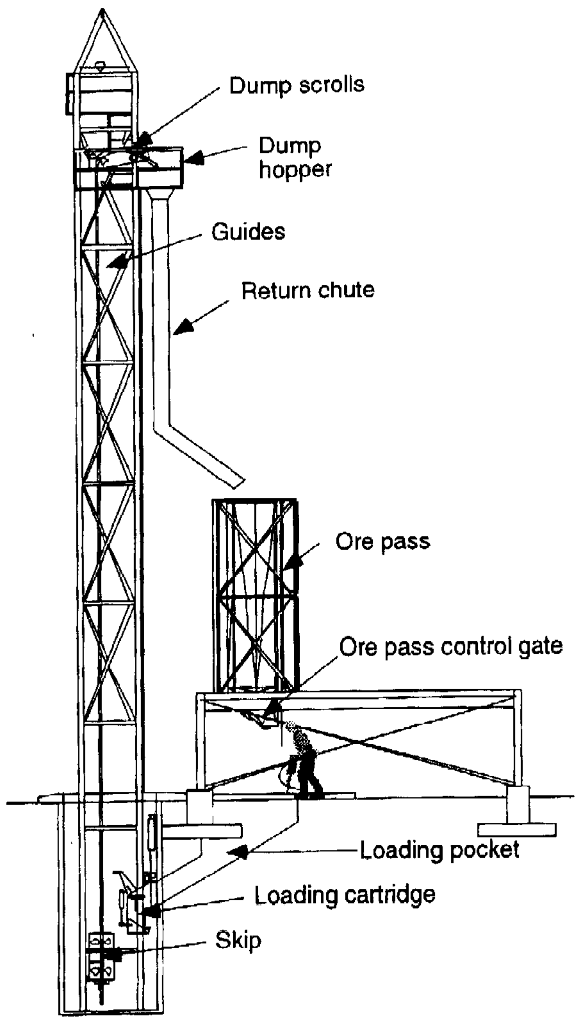

Figure 3—Hoist tower and headframe.

Windows-based human-machine interface (HMI) software and programmable controller technology are used for hoisting automation. A General Electric Fanuc series 90-30 programmable logic controller (PLC) runs the logic for both manual and automatic operation. Wonderware's Intouch HMI software is used to provide the operator interface. This software runs under Windows 95 on an industrial Pentium touchscreen PC. A control panel is currently set up to provide the operator interface for operating the hoist manually and automatically.

Figure 4 shows the main process control screen for the hoisting system. Trend graphs are especially useful for evaluating the most effective sensor types and configurations. For example, optical encoders are mounted on the hoisting drum and on the top of the skip. The graph determines the effects of rope stretch and other errors that may occur in sensing the skip's position.

A Simplex model Lilly control system was also installed to study possible interactions and safety issues arising from retrofitting Lilly control and hoisting systems with automated digital control systems. Lilly controllers have been the standard mechanical control device for mine hoist installations since the early 1900's and are still typical at mining operations.

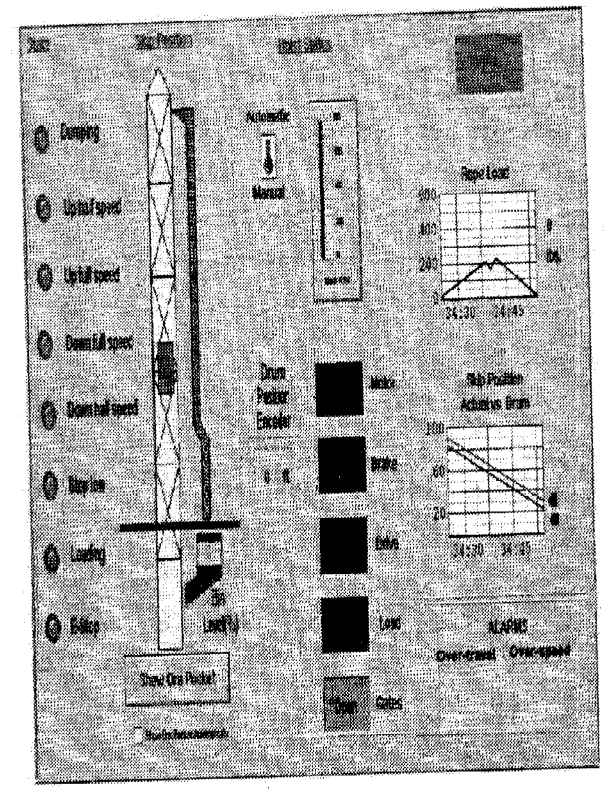

Figure 4.—Main hoist control room.

TEST RESULTS

Field tests are being performed both at the SRL hoist research facility and in a secondary escape shaft of a deep mine in northern Idaho. The purpose of the test series is to validate the functional performance of the sensors and conveyance mounting schemes, evaluate conveyance load and rope tension during normal and abnormal hoisting cycles, and evaluate wireless data transmission schemes.

An abnormal hoist cycle occurs when the conveyance exceeds speed or position limits as defined by the hoist motor controller. As noted earlier, the most serious hazard is a slack rope condition. Figure 5 shows a simulated slack and tight rope condition resulting from an induced guide displacement. At the test facility, a 272-kg (600-lb) skip with a 330-kg (780-lb) payload (total weight of 602 kg [1,380 lb]) was hoisted over a distance of 20 m (60 ft). The effects of acceleration loads on rope tension are clearly seen during the acceleration and deceleration stages at the top and bottom of the cycle. Rope tensile loads from ascending acceleration exceeded the static tension resulting from the total weight of the conveyance by about 30%. Peak tensile forces in the rope exceeded static load by about 80%. Descending acceleration resulted in unweighting of about 67% of the static load and descending deceleration caused unweighting at 22% of static loads.

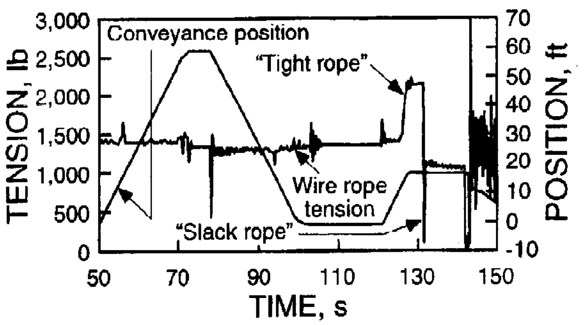

Figure 5.—Tension on wire rope resulting from slack and tight rope conditions

A guide support bracket was then disconnected, and one guide was displaced into the hoistway by about 1.5 cm (0.5 in) about 6 m (18 ft) from the shaft bottom. This figure shows the initial normal hoisting cycle followed by a cycle in which the conveyance became stuck between the guides because of excessive guide displacement. When the conveyance was stopped by the deformed guides, tight rope conditions resulted in rope tensions of about 60% of the conveyance weight. As the winding drum was reversed, a slack rope condition developed while the conveyance remained static. The conveyance then dropped about 1 m (3 ft), suddenly taking up the slack in the rope and causing another tight rope condition that exceeded conveyance weight by 120%. This was followed by another slack rope occurrence at the skip and rope failure. The skip then fell to the bottom.

At the mine in Idaho, field tests were conducted during normal inspection activities. The rectangular shaft is 1,667 m (5,000 ft) deep and has two 1.7-m (5-ft) square hoisting compartments lined with timber lagging. The accuracy and reliability of the top-mounted skip package, as well as the maximum data transmission range, were evaluated using various modem and antenna configurations.

Free radiation as a communications link is based upon a number of desirable characteristics, including ease of installation and accessibility for maintenance, ruggedness, reliability, reasonable cost, and commercial availability of components. Investigators have reported various levels of success with free radiation data links [4]. The key parameters appear to be transmission frequency and antenna configuration. A data link using a 0.5-W, 2.4-GHz modem with a high-gain directional YAGI antenna on the conveyance and a patch-type antenna at the shaft collar provided the best results. Reliable data transmission from the SPB from a depth of approximately 630 m (1,900 ft) was achieved. The top-mounted skip package is currently being evaluated for long-term reliability over the full length of the shaft. A leaky feeder system is being used to transmit data at depths exceeding 600 m (2000 ft). Leaky feeder cable is still the best choice for these depths.

SUMMARY

A monitoring system mounted on the top of the skip was developed and tested. A new wire-rope-mounted load cell was designed to overcome limitations of existing methods for determining slack rope conditions and conveyance weight. Other sensors measure conveyance position and guide displacement. The system is packaged to withstand the rigors of long-term unattended underground operation and to survive the unusually hazardous conditions of o hoisting operations. A state-of-the-art hoisting facility has been constructed. Hoist control is PC-based and incorporates off-the-shelf software that can be readily retrofitted into existing hoisting systems. The facility and conveyance monitoring system allow personnel to assess critical hoist operating parameters and evaluate various safety aspects related to mine hoisting and shaft inspection, such as conveyance load, position, speed, and acceleration; rope tension; and shaft guide misalignment. Field tests showed that the conveyance monitoring system functioned as intended. Reliable data transmission was achieved from depths of 630 m (1,900 ft) in a deep mine shaft, which is sufficient for all but the deepest shafts in the United States.

The major benefit arising from this research will be the prevention of injuries and fatalities related to hoisting operations. With improved monitoring and control technology and the integration of these functions into a broader framework of hoisting process control, research will enable miners to be removed from hazardous locations within the hoisting infrastructure, which will improve the safety of the workplace.

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